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Active System Management Approach for Flexibility Services to the Greek Transmission and Distribution System

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Abstract: New methods for state estimation are required due to the complexity of the topology of transmission and distribution systems, and the predictability in the management of prosumer dispatch. This paper describes a pilot project in Greece that, in accordance with OneNet's architecture, addresses the challenges of congestion and balancing management that system operators face due to the high penetration of renewable energy sources. The respective data requirements and the IT/OT environment are described, as well as the interconnections among the various modules and functionalities. Available resources of the grid's flexibility are identified, and the implementation of an integrated monitoring system based on efficient forecasting of volatile generation and demand is addressed. Congestion management and frequency and voltage control are in the center of interest of the demonstrator where, in close collaboration with system operators, respective network models are being developed.

Keywords: active system management; business use case; distribution system; flexibility; Greek electricity market; key performance indicators; system use cases; transmission system

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1. Introduction

While the electrical grid is moving from being a fully centralized to a highly decentralized system, grid operators have to adapt to this changing environment and adjust their current business model to accommodate faster reactions and adaptive flexibility. This is an unprecedented challenge requiring an unprecedented solution. For this reason, the two major associations of grid operators in Europe, ENTSO-E and EDSO, have activated their members to put together a unique consortium [1].

The project OneNet (One Network for Europe) [2] is funded through the EU's eighth Framework Programme Horizon 2020 [3], and it will provide a seamless integration of all the actors in the electricity network across Europe to create the conditions for a synergistic operation that optimizes the overall energy system, while creating an open and fair market structure. The most relevant network codes when talking about electricity markets are the market codes, as electricity markets are coupled with the system operation. These network codes describe the market design for the European internal electricity market, commonly called the "Target Model" [4–11].

The key elements are:

1. Definition of a common market design for Europe: this means standardized products and key parameters for grid services, which aim for the coordination of all actors, from grid operators to customers.

2. Definition of a common IT architecture and common IT interfaces: this means not trying to create a single IT platform for all products, but enabling an open architecture of interactions among several platforms so that anybody can join any market across Europe.
3. Large-scale demonstrators to implement and showcase the scalable solutions developed throughout the project. These demonstrators are organized in four clusters, including countries in every region of Europe and testing innovative use cases never validated before.

1.1. Scope of the Southern Cluster Demonstrator

The Southern cluster demonstrator consists of the implementation of a pilot project situated in Greece. This pilot project addresses the specific needs of TSOs, DSOs, market actors and consumers, as well as market and regulatory specificities; however, at the same time, it presents an innovative common approach for TSO–DSO coordination for common services and flexibility [1].

In Greece, an advanced forecasting platform evaluating the needs and flexibilities for balancing and congestion management (F-platform) will be developed and implemented in the areas of Peloponnese and Crete. The island of Crete was recently interconnected with mainland Greece and, consequently, with the pan-European interconnected electricity network (Figure 1). The high voltage level is 150 kV for the time being in Crete and Peloponnese while, in the latter area, two new projects of 400 kV OHLs and new substations are planned in the national 10-year network development plan (TYNDP) [12], and they are currently under construction. The Peloponnese area is a mountainous area with high wind capacity; thus, there are a lot of wind parks installed, while the current network capacity is insufficient for the installation of even more wind generation.

Crete was isolated from mainland Greece until July of 2021. Due to the environmental regulation, diesel generation units have to be phased out the in the following years. This is why TSOs included some years ago the AC interconnection with south Peloponnese, primarily, and with Attica through a second HVDC interconnection, at a later stage (scheduled for commissioning by the end of 2023).

The overall objective of the Southern demonstrator is to prescribe, develop, implement and evaluate a pilot project in Greece dealing with balancing and the congestion management challenges facing system operators in the clean energy era, in compliance with OneNet's overall architecture. TSOs and DSOs will share flexibility resources and coordinate their efforts to meet their augmenting regional challenges through grid services stemming from prosumers, aggregators, suppliers and producers: e at the same time, they are optimizing the use of network assets and big data processing tools for network predictability and observability.

The Southern demonstrator will implement efficient forecasting algorithms, grid observability technologies, balancing and congestion management algorithms to evaluate specific strategies and market mechanisms that will finally be incorporated in the OneNet platform. The demonstrator results will be evaluated to provide recommendations for future market reforms in the region and harmonization for a pan-EU electricity market.

Figure 1. The AC and DC interconnections of Crete with mainland.

1.2. Electricity Market Status in Greece

The reformation of the electricity market in Greece started several years ago and was realized via various regulations and directives. Law 2773/1999 [13] set the basis for the liberalization of the Greek electricity market and the regulation of some key points of the national energy policy [14,15]. It also introduced the Regulatory Authority of Energy (RAE), with the objective of monitoring and controlling the electricity market. Law 3426/2005 introduced some additions to Law 2773/1999 that accelerated the electricity market liberalization process [14,15]. In 2011, the Greek government introduced comprehensive new legislation in order to convert the third EU directive into national law and reform the electricity sector. Law 4001/2011 [16] is the foundation of the modern Greek electricity market, as it introduced the transition from the independent system operator model to the independent transmission operator (IPTO) model [14,15]. Greece is set to apply all four markets deriving from the relevant legislation, namely the forward market, day-ahead market, intra-day market and balancing market [14,15]. In the new market structure of Greece, as shown in Figure 2, the Hellenic Energy Exchange (HEnEx) manages the energy markets of physical delivery and the energy financial markets in accordance with the provisions of Law 4512/2018 [17] and its delegated acts. Meanwhile, IPTO, the Greek TSO for electricity established in compliance with Law 4001/2011, manages the balancing market. HEnEx complies with various European licenses, such as the Regulation on Wholesale Energy Market Integrity and Transparency (REMIT), the European Market

Infrastructure Regulation (EMIR), the Markets in Financial Instruments Directive (MIFID II), the Market Abuse Regulation (MAR) and the Nominated Electricity Market Operator (NEMO) (Figure 2). Furthermore, renewable energy sources' (RES) integration into the balancing market is also related to the effective implementation of the role of aggregators in the system, functioning as virtual power plants, pooling RES production and/or electricity consumption of households and selling off their unused power during peak hours, when demand is high [18].

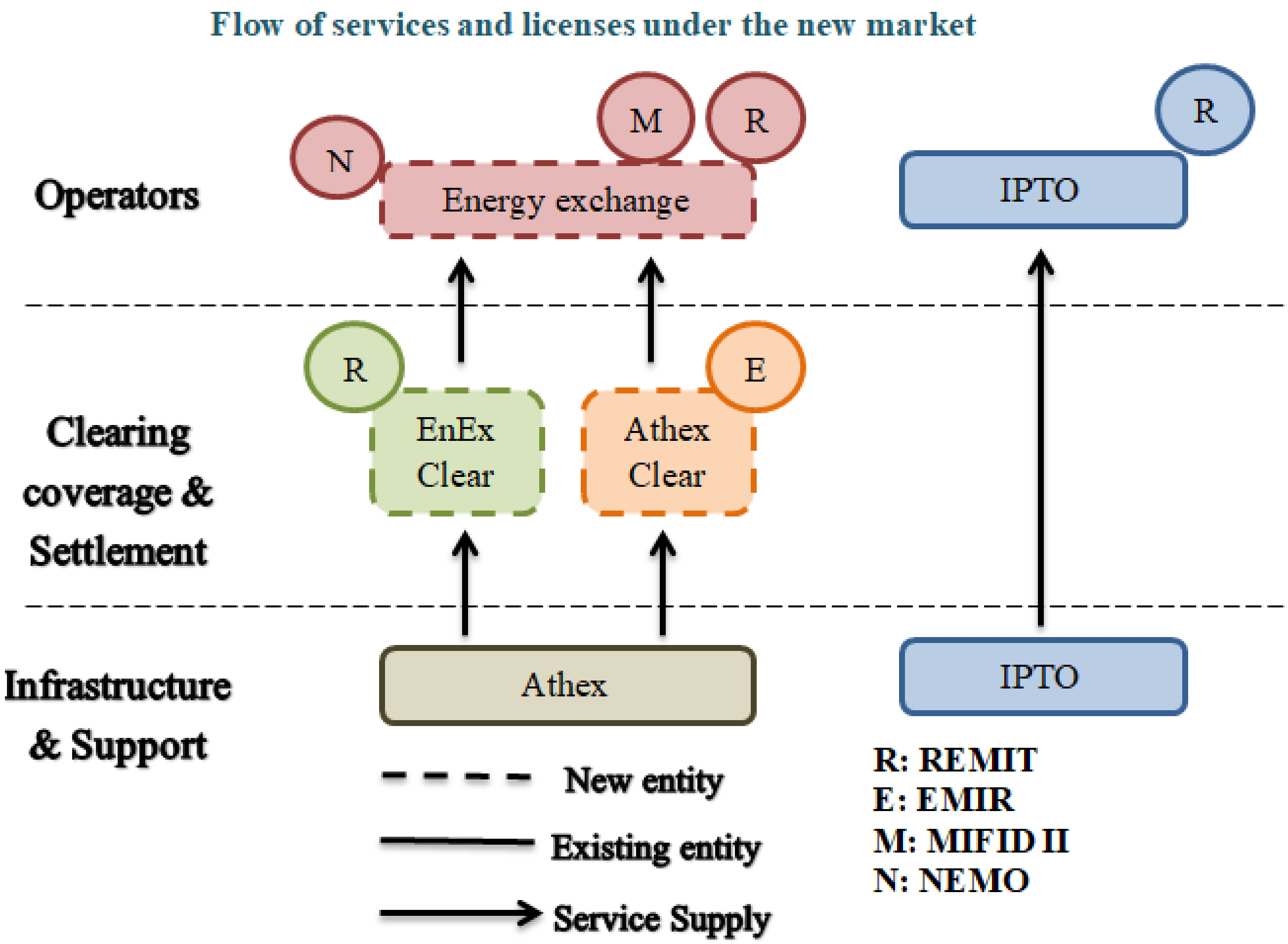

Figure 2. Services under the new market structure in Greece [14].

Since 1 November 2020, the target model applies in Greece. Based on the adopted target model structure, the Greek balancing market includes the balancing capacity market, the balancing energy market and the imbalance settlements [18,19]. The new market design replaced the day-ahead mandatory pool system, which was in operation from 2005. In this central dispatching model, the scheduling process and dispatching bids included unit-based instead of portfolio-based participation [20,21]. The unit-based system comprised of producer participation in the day-ahead market with one energy bid per generating unit, as well as participation in the intra-day market with separate purchasing and selling bids per generating unit [22]. Unit-based participation entailed central scheduling performed by the IPTO in D-1 and real-time balancing conducted by IPTOs, in order to dispatch the units to cover the load and reserves, and to centrally handle system imbalances in generation and demand. Going forward, day-ahead and intra-day markets fall under the authority of the Hellenic Energy Exchange (HEnEx) [15] (Figure 3). The Greek wholesale power market also includes the acquisition of auctions, explicitly for physical transmission rights (PTRs), to serve cross-border exchanges with all the interconnected countries [18].

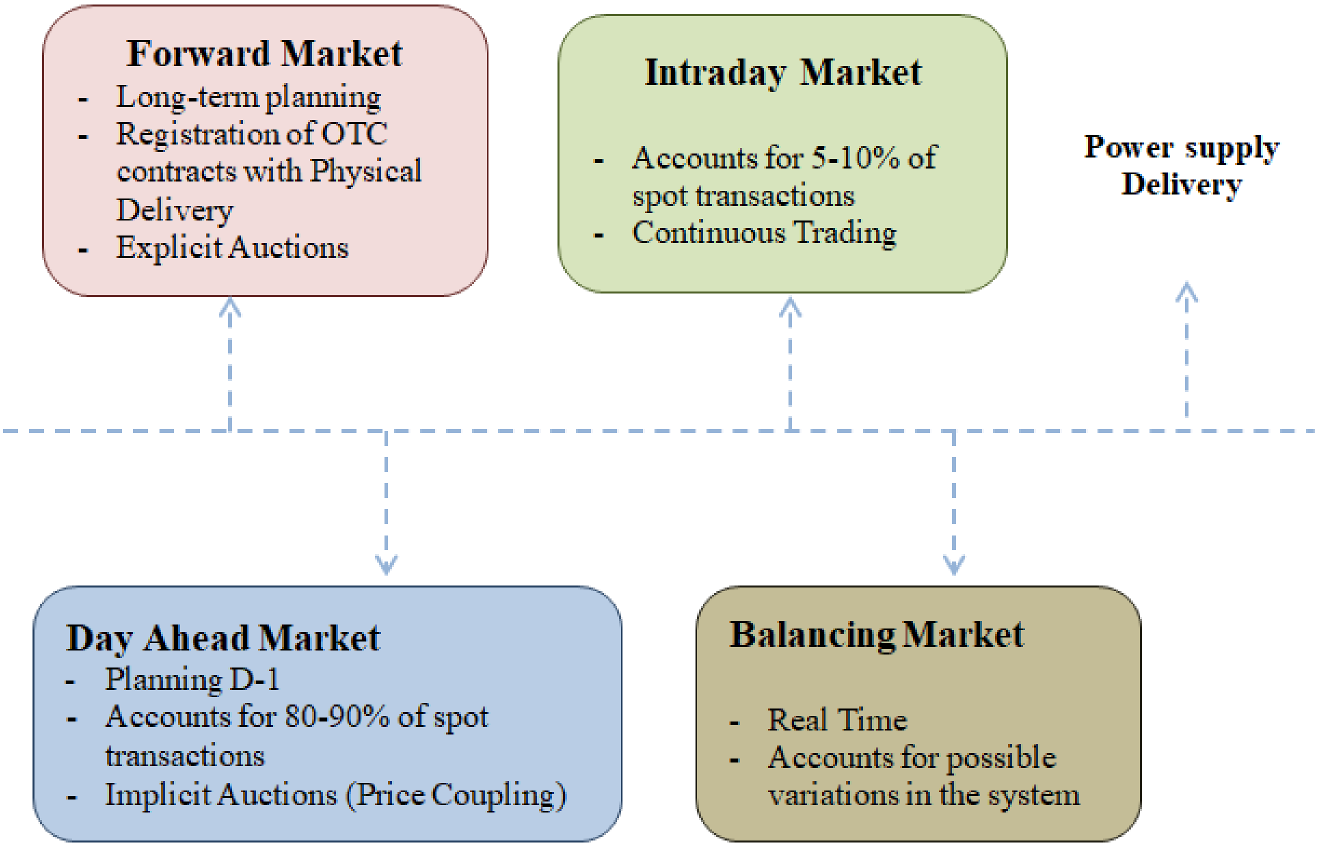

Figure 3. The new market structure in Greece [15].

In the same framework, the day-ahead market is an hourly spot market, balancing demand and supply via electricity prices, reflecting the highest generation bid needed to balance the lowest willingness to pay of load representatives. This market allows participants to submit electricity transaction orders with the obligation of physical delivery the next day. Participants can also declare the energy quantities corresponding to forward market product transactions in the day-ahead market, irrespective of commitments through the forward products wholesale market, or outside of it. The delivery day (D) consists of 24 purchased time units [15,23]. Gate opening is at 10:30 (D-1) and lasts for 150 min as the gate closure time is at 13:00 (D-1). Hourly bids are the most common type of bids in power exchanges, and the essential information required for each bid includes the participant's details, type of bid (sale or buy), an hour of the day, quantity and price [15,23]. Market participants in the HEnEx submit their bids throughout the transaction system, determining the quantity and the price they are willing to sell or buy.

The balancing market is critical for the safety of the system as it has not only economic, but also physical effects. Today, it has a small market share (up to 5%), but this will increase as the penetration of RES increases. The balancing market in Greece is based on the unit based/central dispatching model. In Greece, the system operator selects the bids (which are given per production unit) with the lowest price on the basis of on an optimization algorithm, and issues corresponding orders to each production unit are selected for the provision of each service. Specifically, in the first stage, it is ensured that the system has sufficient capacity to provide balancing services in accordance with the operator's estimates and then, when necessary, the required orders are issued to the entities that provide balancing services. Entities that provide balancing services submit bids to the market per unit, per load zone and per interconnection border. The balancing market is implemented through three separate markets, namely the balancing capacity market, the balancing energy market and the imbalances settlement market [19,23] as is presented in Figure 4.

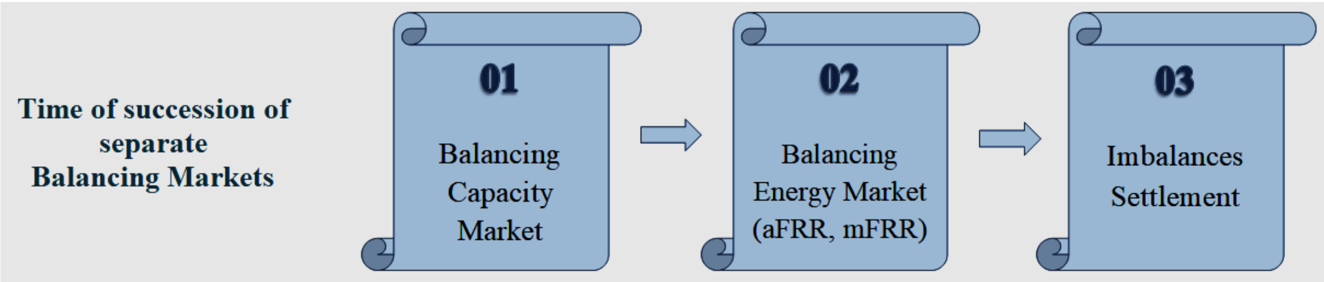

Figure 4. The balancing market structure in Greece [23].

In the framework of the balancing capacity market, the system operator determines the number of required reserves for each balancing capacity product that is deemed necessary for each allocation period, and participants submit bids for these products, provided they have the technical capacity to provide them [19,23]. Participation in the balancing capacity market takes place prior to real-time. The market design prescribed three key balancing capacity products: upward and downward frequency containment reserve (FCR), upward and downward manual (non-automatic) frequency restoration reserve (mFRR) and upward and downward automatic frequency restoration reserve (aFRR) [19,20,23]. Participants are compensated for the balancing capacity quantity that corresponds to them from the market clearing on a pay-as-bid basis every 30 min, and participants are required to commit the respective capacity in order to maintain a safe margin for system balancing in real-time. The dispatch and balancing market settlement period are 15 min, compared to the current imbalances settlement scheme which is one hour [19,20,23].

The volumes of FCR, aFRR and mFRR reserves are awarded to the market participants through the integrated scheduling programming (ISP), based on the requirements published by the TSO on a 30 min granularity. The participants submit volume-price balancing capacity offers per reserve product, provided that they are eligible, technically and operationally, and have the capacity available for reserves. The offerors are dispatchable generating units. Demand response, electricity storage systems and RES are not yet eligible to offer reserves; however, regulatory, technical and operational preparations are ongoing to allow such participation in the reserve offerings by 2022 (for DSR and RES, whereas for storage regulation, this is pending).

In the context of the balancing energy market, all entities that can provide balancing services are required to submit bids to the market for the necessary balancing energy products, the amount of which is determined by the system operator. Close to real-time, the operator estimates, where activation of the upward or downward manual frequency restoration reserve (mFRR) is necessary, and then issues the corresponding orders based on the lowest priced bids [1]. In real-time, the entities that can provide aFRR receive automatic orders for activation of the lowest priced bids in order to ensure the balance of the system, under the limitation of protecting the safe operation of the system. This is a process similar to automatic general control (AGC). Energy is compensated at a marginal price per balancing energy product, except for reallocation cases, when it is compensated at the bid price and every 15 min. Imbalances settlement takes place post real-time, and focuses on the compensation or charge of the energy arising from any imbalances of the participants in the balancing market from the last schedule of the market and/or the dispatch orders. The imbalance settlement procedure defines the remunerations and, generally, the settlement for balancing energy, balancing capacities and imbalances. The remuneration basis results from the RTBM algorithm that implements the balancing energy market. The imbalance settlement period was already set to 15 min from 1 November 2020 [19].

The core of the balancing market is the ISP, which is a process carried out by the system operator to shape the dispatch schedule of units and allocate the balancing capacity to the entities that provide it [19]. The ISP is carried out on a schedule three times, i.e., once immediately after the clearing of the day-ahead market, and two more times after the clearing of each one of the two intra-day auctions, carried out according to the framework of the intra-day market [19]. It may also be carried out on demand if the operator deems that there are significant changes during the operation of the system. The ISP clearing takes place for 30 min dispatch periods. The results of the ISP clearings are not binding for its first execution. They are binding for the first 24 dispatch periods of the dispatch day for the clearing after the first intra-day auction and are binding for the last 24 dispatch periods of the dispatch day for the clearing after the second intra-day auction. Participants, before the clearing of the first ISP, submit bids for both the balancing capacity and for the balancing energy, for each 30 min dispatch period.

For the clearing of the balancing energy market, the operator converts the 30 min energy bids of the participants into 15 min bids. Participants may submit only improved bids in relation to the bids submitted at the first ISP, namely bids with a lower price in the case of a production unit, or bids with a higher price in the case of load [19]. The last available 15 min energy bids are received for participation in the real-time balancing energy market, as mentioned above. At this point, it should be noted that the design of the balancing market takes into consideration all potential balancing energy supply sources, namely conventional units, RES units and load, in the case of aggregators, which can provide balancing capacity and energy products after the conduct of the relevant pre-selection tests [19]. Finally, the imbalances settlement takes place when the required metering data are available, closing the cycle of balancing market processes [19].

Several studies were taken into consideration for the better outcome of the current work [24–26]. In [24], it is proposed that the available transfer capacity (ATC) mechanism that dominates cross-border trading is to be replaced by the flow-based (FB) approach across Europe. In this case study, the Southeast Europe (SEE) region is taken into consideration; and the tests perform, compare, and evaluate the effectiveness of each method for the SEE region. A recent study [25] explores the time period before the implementation of the target model, which took place on November 2020, and the first nine months of its execution. Empirical findings indicate a relatively successful implementation of the target model in Greece, with price disorders mostly met in the balancing market. Additionally, in [26], an analytical review of all the aspects governing the European balancing market integration is presented, providing a detailed description on the European regulatory framework on this topic: it is concluded that further effort is still required to move from a regional level to a European-wide real-time balancing market.

2. Description of the Platforms, Requirements and Scenarios in the Pilot Projects for Flexibility Services to the Greek Transmission and Distribution System

2.1. F-Channel Approach

The F-channel is foreseen as a web-based, client server application, which will enhance active power Management for TSO–DSO coordination using artificial intelligence (AI) methods and cloud-computing approach.

The availability of climatic data models in recent years opened the possibility for the continuous prediction of various parameters relevant to the power system needs. Predicting wind speed and solar insolation patterns throughout the yearly season with a very high geo resolution is possible through AI methods and usage of cloud computing techniques/environment. Demand response forecasting is also worth noting, as well as recent attempts in modeling icing on power lines and wind turbines with the usage of historical climatic data models, which can contribute a lot to the power grid operational planning, its flexibility and reliability estimations and smooth operations.

For the purpose of this project, a similar approach is used. Historical weather data in the hourly resolution is analyzed, and appropriate predictions for the energy output of each particular predefined point of interest (POI) is given. Once the model is established, sensitivity shall be tested against real-time data and adjustments using AI algorithms are to be applied for optimizing the efficiency of the model. On top of this, the model uses the most advanced numerical weather predictions (NWP)-based weather forecasts, provided by the external professional weather forecast provider in order to fine tune and further improve forecasting outcomes. In further stages, integration with real-time weather data is analyzed and the possibility to make a sustainable solution for industrial partners is analyzed and proposed.

2.2. Active System Management (ASM) Approach and Regulatory Framework

The cost-effective and secure management of the energy systems is achieved by DSOs and TSOs, through the employment of a critical collection of methods and technologies known as active system management (ASM). In order to address challenges affecting system operation, it entails the use and improvement of smart and digital grids, operational planning and forecasting processes and the capacity to modulate, in different timeframes and distinct areas, generation and demand encompassing flexibility instruments (toolbox). This ensures proper integration of renewable energy sources (RES), a high share of Distributed Energy Resources (DER), as well as the integration with energy markets. Figure 5 illustrates the services for various purposes that can be provided by flexibility, which is a component of ASM. Flexibility benefits of smart grid innovations that were developed and implemented in the context of European research and innovation programs are presented in recent research work [27–34], contributing to the increase in renewable energy sources penetration, to the network investments deferral and to the enhancement of the efficiency of the system operation, avoiding generation capacity oversizing.

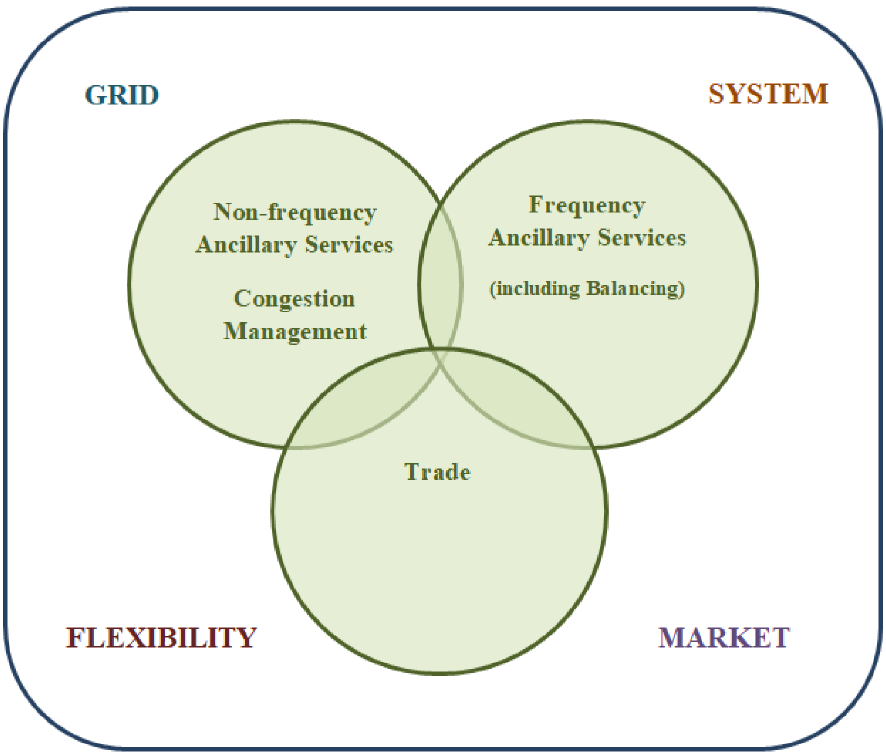

Figure 5. Flexibility services [1].

The connection of renewable energy generation to distribution grids impacts power flows and voltage stability across all grids. While advancements and cost reductions in information and communication technology (ICT) enable DSOs to greatly improve the supervision of their grids at acceptable costs, distributed generation offers new potential for active management in distribution grids as well. Due to fluctuating power flows, both of these variables increased the potential and necessity to execute active power and reactive power management in distribution networks.

Additionally, through appropriate coordination mechanisms established between TSOs and DSOs, distributed generation should have the same opportunities as transmission-connected generation to maximize their value and their revenue by taking part in grid balancing and congestion control. Recent proposals for European regulatory developments and the Clean Energy Package support these new activities, and the use of flexibility services for congestion management and non-frequency ancillary services in the distribution grids by DSOs, when the national framework permits. Ancillary services are services provided to DSOs and TSOs to keep the operation of the grid within acceptable limits for the security of supply and are delivered mainly by third, or by the TSOs and DSOs themselves (topology changes and integrated network components). Ancillary services are classified as:

(a) Frequency ancillary services (mainly for balancing).
(b) Services for congestion management.
(c) Non-frequency ancillary services, such as voltage control and grid restoration, among others.

ASM refers basically to the actions taken by TSOs and DSOs to ensure that the grid operational parameters are within satisfactory ranges. It encompasses the operational planning processes, the required observability and controllability of the grid, the necessary data exchanges and the interaction with market parties delivering those services.

The respective regulatory framework is analyzed from the national point of view in Greece where the demonstration will take place, which includes the following:

(a) Article 32.1 of Electricity directive (CEP), DIRECTIVE (EU) 2019/944 [5].
(b) System Operation Guidelines (SOGL) [9].
(c) Electricity Balancing Guideline (EBGL) [8].
(d) Guideline on Capacity Allocation and Congestion Management (CACM) [10].
(e) Network Code on Requirements for Generators (RfG NC) [35].
(f) Demand Connection NC [36].

2.3. Proposed System Layout and Architecture

The simple proposed system layout is given in Figure 6. Special care is taken in establishing data exchange between weather (energy) forecasting modules and planning (grid analysis) module, in order to address the weather-induced variability in RES generation and demand in the best possible way.

Based on needed computing resources for energy forecasts, a cloud computing engine is considered for this project and will be further used for modeling purposes if needed. On the following diagram, basic architecture of the proposed web application is given:

1. A similar computing engine will be developed for grid analysis and calculation purposes. Regarding data storage, databases and storage accounts are required. Allocated computing resources shall be split into two groups: continuously and per computation/transaction allocation. Power grids, as well as any necessary market data, will be stored on the dedicated protected server, physically located in Energo Info Group (EIG) premises or another partner's premises, upon agreement. However, power system analysis calculation would still be performed on the server engines l, making the app very fast and of a light capacity at the same time.
2. The calculation engine will be robust enough to handle transmission, distribution and any customized microgrid topology with its calculations.
3. The database is to be structured in a traditional RDBM rational model. A geographical component-spatial will be implemented, since main datasets are geographically oriented. This provides easier representation, aggregation and query of all datasets. Display of geospatial data is to be provided by developed middleware supporting web map services (WMS) and web feature services (WFS).
4. Special care is addressed to the security of server infrastructure. Server access codes to the development environment shall be encrypted with secure shell (SSH) keys. Furthermore, access shall be restricted to specified IP address ranges. Access to the web app on the user side is to be limited to verified accounts created by an administrator.

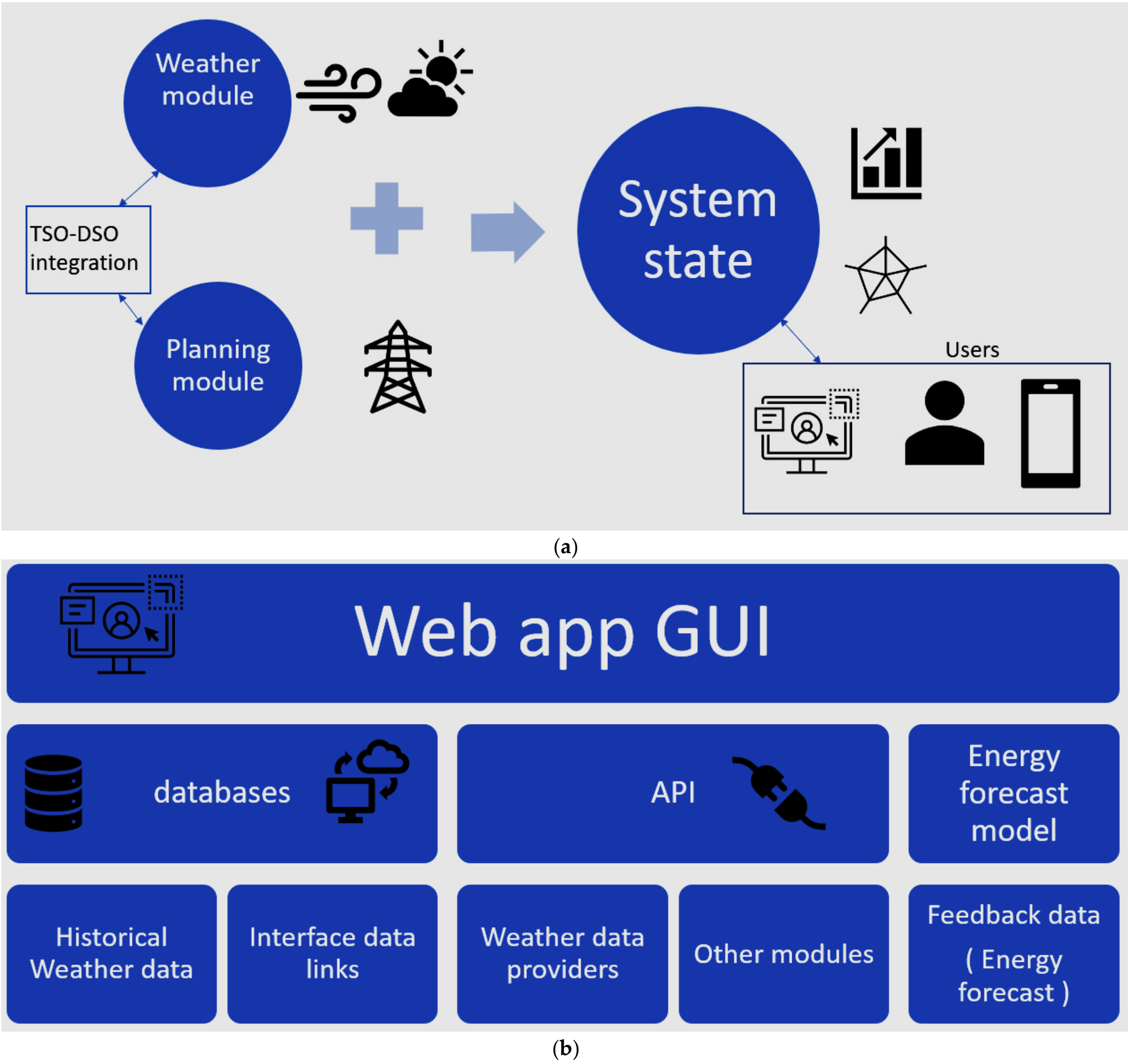

Figure 6. (**a**) Proposed system layout for the F-channel; (**b**) Cloud computing engine.

2.4. AI Algorithms and Methods

Initially, historical weather data in 1 h resolution shall be used to obtain behavior patterns of climatic parameters (daily, monthly, seasonally) throughout the region of interest. For this purpose, various ERA5 climatic datasets shall be used, as well as AI algorithms applied in combination with terrain orography data. These data shall provide a starting point for creating various case studies i.e., all RES locations can be monitored through time, and critical scenarios shall be identified based on AI algorithms. Since ERA5 [37] models can provide various wind speed parameters (2 m height, 100 m height, wind gust), these variables shall be tested and adjusted accordingly to reduce bias when compared against operational data. Modeled results shall be compared with operational data from TSO/DSO and appropriate model calibration shall be provided based on deep learning AI algorithms.

In the second stage of project, the implementation model must be linked with a forecast weather application programming interface (API), with various climatic parameters relevant to production acquired. Stakeholder's data shall be implemented based on a customized interface. Usage of forecasted data enables the calculation of line ratings, based on wind and temperature. All relevant calculations shall be conducted using highly optimized, vectorized CPU-oriented procedures. Core functionalities are to be implemented using Python and C programming language, with the GUI interface made in a Flask environment.

Calculation models shall comply with all relevant standards and procedures. For instance, wind production forecast is conducted in compliance with the IEC 61400 series; and conductor ampacity is calculated in compliance with [38]. In further stages of the project, upon feedback with site measurements, models can be adjusted accordingly.

2.5. Distribution and Microgrid Points of Interest (POIs)

The F-channel will model the transmission system, the distribution system and microgrid levels, with the customizable aggregations on the DSO, TSO and balancing group topological aggregation level layer, allowing DSO–TSO coordination in the field of flexibility and congestion management services through improved short term power system planning in both system operators. At the same time, the prosumer's active inclusion and role as an equal market participant is allowed. Full utilization of the vertical data and services flow would cover all vertically connected entities.

2.6. Data Requirements

The following set of data was collected and processed for F-channel development and implementation.

2.6.1. Network Models Data

Network models of transmission system were submitted by IPTO. The network models of the distribution system will be modeled with available data and proper equivalents will be used for the simulation purposes.

2.6.2. Geospatial Data

GPS coordinates, locations of power system elements, including detailed routing and positions of each tower for the analyzed wind power plants (WPPs) and overhead lines (OHLs) are as follows:

- Substations (GPS coordinates describing the SS area).
- Wind parks (GPS coordinates describing the WPP area).
- Solar parks (GPS coordinates describing the SPP area).
- 400 kV HVAC lines (GPS coordinates of at least the starting and ending point of a line).
- 150 kV HVAC lines (GPS coordinates of at least the starting and ending point of a line),
- 20 kV HVAC lines (GPS coordinates of at least the starting and ending point of a line),
- HVDC lines and cables of interest (GPS coordinates of at least the starting and ending point of a line).

Power system GPS data, as well as GPS data on selected POIs, will be used for GIS visualization, localization of weather and energy forecasts:

- GPS points for OHLs and cables, including the start and endpoint, together with the corresponding substation names. It is necessary to indicate if the circuit is single or double, and if parallel lines are connecting the same POIs. Conductor type and characteristics (diameter, weight and rated ampacity), as well as the type of conductor bundle arrangement (2-bundle, 3-bundle, etc.).
- GPS points for substations that define the endpoints of the substation surface, describing the surface of the plant.
- GPS coordinates of each WP tower of the analyzed wind parks.
- GPS coordinates of each OHL tower (or preselected number of towers) of the analyzed OHL.
- List of proposed interconnection lines (TSOs).

2.6.3. Technical Data for Wind Turbines and PV Parks

After selecting proper POIs, TSOs and DSOs should provide technical specification for each wind turbine type installed in the system if it is available. Otherwise, generic standard data will be used by TSOs and DSOs instead.

Being more specific, the technical specification data needed are as follows.

1. For each turbine: the turbine type, longitude, latitude, altitude, rotor diameter, tower height, rotor height, A-factor, form factor c, annual average wind speed, vertical average shear component, extreme wind speed (10 min average), survival wind speed (3 s average), automatic stop limit (10 min average), rated power, rotor speed, rated wind speed (30 s average), cut in wind speed (3 s average), cut out wind speed (10 min average), restart wind speed (10 min average), power curves.
2. For each section of PV panels in solar parks: longitude, latitude, altitude, power conversion factor, tracking or static panels, panel's tilt angle.
3. For selected overhead lines: longitude, latitude, altitude, tower type, tower total height and wire height. Additionally, it is important to provide the overhead line route cross-section (in PDF preferably) for the OHLs that will be covered by novel forecasting.
4. For proposed critical lines (DSOs and TSOs): the names of the two substations they connect, the voltage level, the number of circuits and the parallel OHL index.
5. For all VRE production units (DSOs and TSOs): longitude, latitude, altitude, voltage level and installed capacity.

2.6.4. Historic Energy Data

- Historic production data for wind and solar for each of the concerned plants: hourly production for the last 10 years (or any other available period).
- Historic energy data for consumption (for defined SSs): hourly consumption for the last 10 years (or any other available period).

2.6.5. Historic Weather Data

Historic weather data is measured and forecasted data is related to the energy production/consumption of the analyzed POIs in Greece. These data (measured and forecasted) for the last 10 years (or any other available period) can be provided by Greek authorities and/or TSOs and DSOs.

2.6.6. Copernicus Climate Change Service Reanalysis Data

Copernicus datasets are implemented and maintained by the European Centre for Medium-Range Weather Forecasts (ECMWF) and represent data available for the general and scientific public [37]. For the selected POIs the following historic data will be collected where available:

- Pressure/wind speed 10 m
- Pressure/wind speed 100 m
- Pressure/wind
- Clouds
- Convective clouds
- Low clouds
- Rain
- Temperature
- Soil temperature
- 500 hPa temperature
- 850 mb temperature
- Visibility
- Soil wetness
- Snow
- Snow depth

- Rain/snow
- Daily precipitation (acc)
- Daily snow (acc)
- 700 hPa temperature
- 500 hPa wind
- Solar radiation

2.6.7. Energy Policy Information

Information on applicable EU Directives and Regulations that are of interest for TSO–DSO coordination [1] were collected. The data is pre-processed, and in cases where appropriate, stored on a dedicated database on the production server. Allocated computing resources are split into two groups: (i) continuously allocated and (ii) allocated per computation/transaction. Power system analysis calculations during the demonstration/test period will be performed on cloud-based and other AI algorithm-based calculations.

3. Business Use Case, Products and KPIs of the Southern Cluster

The F-channel seeks to improve identification of the available flexibility resources, focusing on DSO voltage levels, together with the improved identification of the power system flexibility needs. These needs are focused on a TSO voltage level grid, on a longer period and wider geographical scope than the one being utilized today, through simultaneous DSO, TSO and grid simulation backed up by AI-based calculation engines.

3.1. Business Use Case and KPIs for the F-Channel Demonstration in Greece

The business use case (BUC) that was identified for the F-channel platform and will be demonstrated though the Greek demonstration is named “Enhanced Active Power Management for TSO–DSO coordination”. This BUC is correlated with products and system use cases (SUCs) in collaboration with OneNet partners (Table 1).

Table 1. Correlation of system use cases (SUCs) and Products.

SUC	Product/s Involved
Improved congestion management process on the TSO and RSC side (improved short-term forecasts, contingency analysis and capacity calculations through utilization of the information from DSOs and/or local microgrid operators)	Predictive congestion management for the TSO/DSO product
Improved frequency control on the TSO side	Power regulation through mFRR and RR–active power product
Improved voltage control on the DSO and TSO side	Reactive power support product
Identification of the available flexibility resources from DSO and microgrid voltage levels	Predictive congestion management for the TSO/DSO product Power regulation through mFRR and RR–active power product Reactive power support product
DSO, DG and microgrid POI management (point of interest updates, technical data, historic data, forecasted data, etc.).	N/A
Change view–different aggregation level simulations (energy predictions and system state predictions for different aggregation levels of DSO grid and local microgrid): unit level (distributed generation unit, OHL tower/section), plant level (solar park, wind park, OHL, substation), local microgrid level (part of the DSO grid), DSO/TSO grid level calculations	N/A

3.2. Description of the Business Use Case

The scope of this business use case is the improved identification of the available flexibility resources, focused on DSO voltage levels, together with the improved identification of the power system flexibility needs. These needs are focused on a TSO voltage level grid, on a longer time-span and wider geographical scope than the one being utilized today, through a simultaneous DSO, TSO and grid simulations backed up by AI-based calculation engines.

Additionally, the objectives of this business use case are:

- Frequency stability.
- Load flow and contingency monitoring and predictions.
- Predictive congestion management for maintaining secure and stable power system operation.
- Cost-effective operation of the system.
- Early warning on a hazardous power system regime.
- Better flexibility service providers (FSPs), planning and managing flexibility resources.
- Better energy predictions and power system state predictions.
- Improved identification of the available flexibility resources on all power system levels.
- Improved prediction of the system flexibility needs.

The F-channel application which will be developed will be capable of identifying flexibility resources more precisely and simultaneously for both DSO and TSO grid levels, mainly under OneNet, focusing on the lower voltage levels' prosumers that are usually not covered by detailed energy predictions. Additionally, it will be capable of identifying the power system state (the need for the flexibility services) in a much more precise manner and over a longer time period than is being achieved today, covering a wider geographical scope by national control centers and/or RSCs. The aim is to improve production/consumption predictions for different voltage level entities, from residential prosumers to the centralized WPPs and SPPs connected to the distribution grid or any local microgrid (local energy communities) through improved forecasting efficiency, from increased spatial resolution NWPs and AI integration into the short to mid-term power system planning simulations.

- Improved identification of the available flexibility resources.
- Improved prediction of the system flexibility needs.

The application itself will not depend on the exact product being utilized within the market, or the market model itself (it will be possible to use it for different services and products, and different market models). It will focus on a predictive management of products, and on a need for those products. There is a possibility for products from a microgrid and DSO levels to be recognized and available for utilization on higher voltage levels (TSOs and RSCs), as well as on the administrative aggregator's level:

- Improved system-oriented predictions and forecasting efficiency, which will limit the volume of flexibility needs.
- Identification of the flexibility resources to procure grid services, and
- Better FSPs planning and managing flexibility resources.

The main foreseen benefits/functionalities related to this particular business case are as follows:

- Identification of the available flexibility resources from DSO and microgrid voltage levels.
- DSO, DG and microgrid POI management (point of interest updates, technical data, historic data, forecasted data, etc.).
- Change view–different aggregation level simulations. Energy predictions and system state predictions for different aggregation levels of the DSO grid and local microgrid: unit level (distributed generation unit, OHL tower/section), plant level (solar park, wind park, OHL, substation), local microgrid level (part of the DSO grid), DSO/TSO grid level calculations).

- Improved congestion management process on TSO and RSC side (improved short-term forecasts, contingency analysis and capacity calculations through the utilization of the information from DSO and/or local microgrid operator).
- Improved frequency control on the TSO side.
- Improved voltage control on the DSO and TSO side.
- Improved system adequacy on the DSO and TSO side.
- Improved islanded operation on the DSO and TSO side.

In Table 2, the KPIs are presented.

Table 2. Key performance indicators for the business use case.

Name	Reference to Mentioned Use Case Objectives
Energy production prediction error	- Frequency stability - Load flow and contingency monitoring and predictions - Predictive congestion management for maintaining secure and stable power system operations - Early warning on hazardous power system regimes - Better FSPs planning and managing flexibility resources - Better energy predictions and power system state predictions - Improved identification of the available flexibility resources on all power system levels - Improved prediction of the system flexibility needs
Load prediction error	- Frequency stability - Load flow and contingency monitoring and predictions - Predictive congestion management for maintaining secure and stable power system operation - Early warning on a hazardous power system regime - Better FSPs planning and managing flexibility resources - Better energy predictions and power system state predictions - Improved identification of the available flexibility resources on all power system levels - Improved prediction of the system flexibility needs
Load flow prediction error	- Frequency stability - Load flow and contingency monitoring and predictions - Predictive congestion management for maintaining secure and stable power system operation - Early warning on a hazardous power system regime - Better FSPs planning and managing flexibility resources - Better energy predictions and power system state predictions - Improved identification of the available flexibility resources on all power system levels - Improved prediction of the system flexibility needs
Capacity prediction error	- Load flow and contingency monitoring and predictions - Predictive congestion management for maintaining secure and stable power system operation
Transmission losses prediction error	- Cost-effective operation of the system
Contingency identification rate	- Better energy predictions and power system state predictions - Predictive congestion management for maintaining secure and stable power system operation - Early warning on hazardous power system regimes
Early warning on hazardous power system regimes rate	- Better energy predictions and power system state predictions - Predictive congestion management for maintaining secure and stable power system operation - Early warning on hazardous power system regimes

The interactions of the business use case are presented in the following Figure 7.

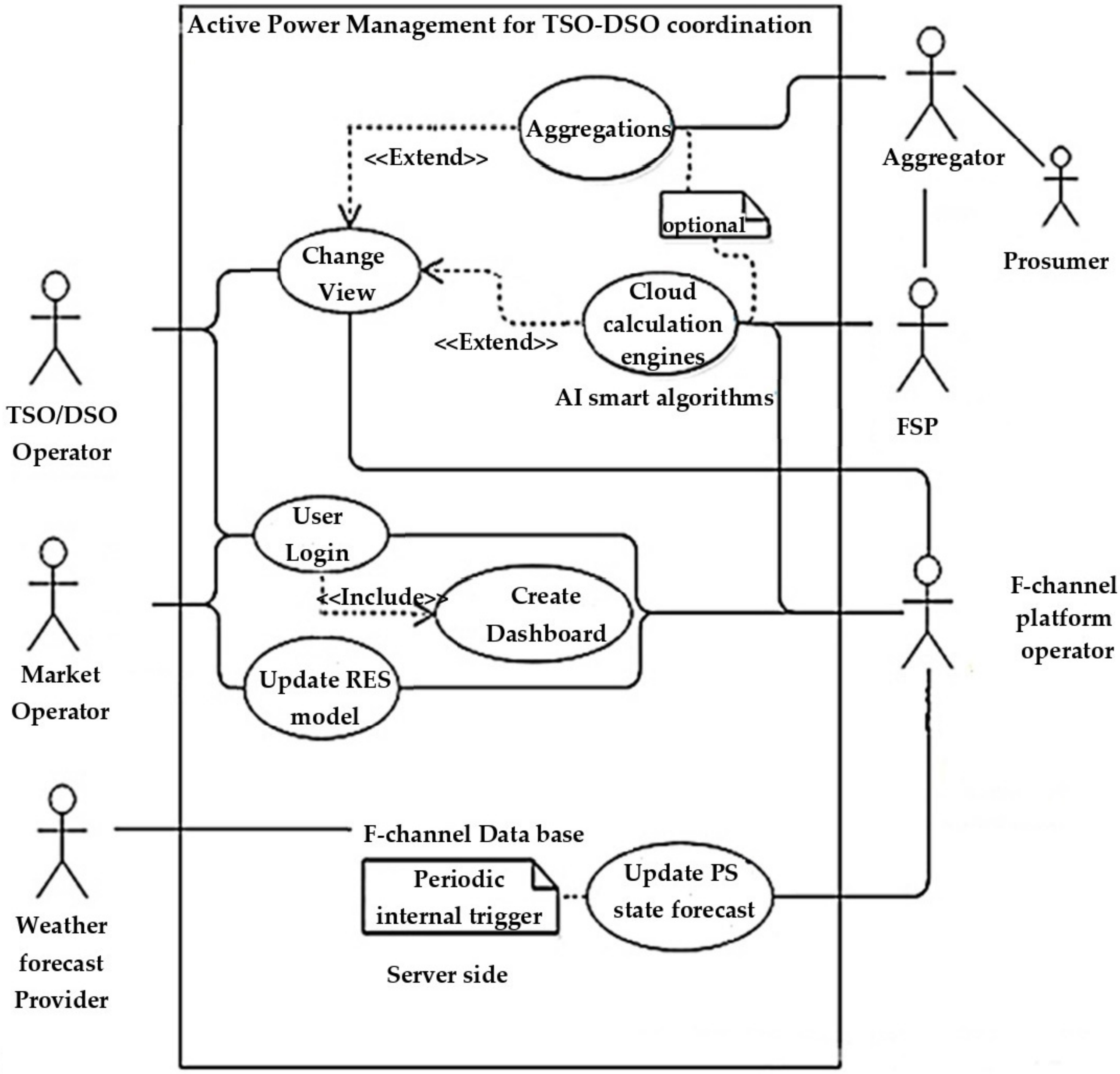

Figure 7. Diagram of the business use case.

The market process diagram is presented in the following Figure 8.

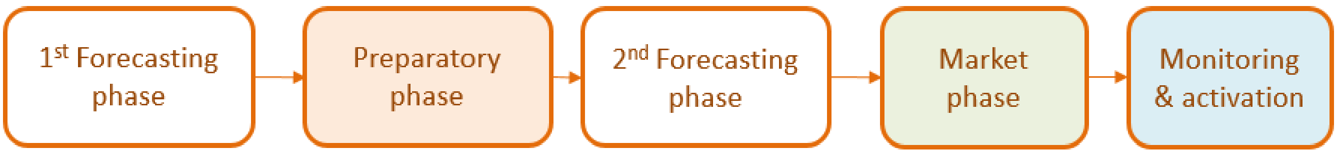

Figure 8. The market process diagram of the Business Use Case.

The following steps reflect the actions in Figure 8.
Forecasting phase:

1. Makes a forecast of potential flexibility resources.
2. Exchanges information about potential flexibility resources.
3. Informs potential flexibility resources.
4. Optimizes portfolio.

Preparatory phase:

1. Defines the prequalification requirements.
2. Sends the prequalification requirements.
3. FSP notifies that he is interested in providing flexibility services.
4. Sends the prequalification requirements.
5. Forwards the fulfilled prequalification requirements.
6. Valuation of the product and grid prequalification requirements.
7. Requests additional prequalification information.
8. Sends additional prequalification information.
9. Accepts/rejects registration on market.
10. Notifies of prequalification result.

2nd forecasting phase:

1. Makes a forecast of possible congestion areas.
2. Exchanges information about possible congestion areas.
3. Informs possible congestion areas.
4. Publishes the possible congestion areas.
5. Optimizes portfolio.
6. Makes a forecast of the grid status.
7. Checks power flows.
8. Detects possible congestions.
9. System reconfiguration.
10. Assesses the amount of flexibility required.
11. Exchanges information about the amount of flexibility required.

Market phase:

1. Offers active power flexibility products.
2. Informs the amount of flexibility required.
3. Capacity bids selection.
4. Selects the bids that may be a solution.
5. Sends the capacity bids.
6. Technical evaluation of the bids.
7. Accepts bids.
8. Sorts the bids by a merit order list.
9. Sends the accepted/rejected capacity bids.
10. Notifies the result and, if accepted, commits the FSP to make bid available on the ST market.
11. Selects the bids that may be a solution.
12. Sends the bids.
13. Technical evaluation of the bids.
14. Accepts bids.
15. Sorts the bids by a merit order list.
16. Sends the accepted/rejected bids.
17. Checks the location of the bids.
18. Notifies the result and, if accepted, commits the FSP to make bid available on the ST market.
19. Sends the information of the bid.
20. Evaluates grid constraints.
21. Accepts/rejects bid.
22. Notifies the result and, if accepted, commits the FSP to make bid available on the ST market.

Monitoring & activation phase:

1. Sharing of accepted bids.
2. Checks grid constrains.

3. Informs what bids can or cannot be activated.
4. Allowing/not allowing bid activation.
5. Informs the result.
6. Informs the activation of the bid.

3.3. Scenarios to Be Tested in the Greek Demo

The scenarios to be tested in the Greek demo are presented in Table 3.

Table 3. Scenarios to be tested in the Greek demo.

Scenario	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Contingency identification and mitigation	Potential contingencies are identified up front (predicted) in the distribution and transmission grids via improved power system state prediction tools. The flexible resources are coordinated by the DSO and TSO to provide active power regulation services in order to relieve the local contingency of the grid. The flexible resources participating in this scenario were already awarded by the market (declaring their availability through bids), and their bids were pre-qualified by the DSO or TSO in order to participate to the predictive short-term local active product.	-FSP (energy storage, PVs) -Aggregators -Prosumers -DSOs -TSOs	Predicted contingency in the DSO or TSO grid.	High-resolution NWP with the extended geographical coverage and look into the future. Available DSO and TSO voltage level forecasted grid models.	Flexible resources will increase or decrease their active power output to shift an amount of energy to resolve contingency in the distribution or transmission grid.
Coordinated voltage control	Potential overvoltage or undervoltage severe states are identified, predicted up front. These are the states that can endanger overall power system voltage stability. In case of voltage instability, the DSO will coordinate the flexible resources to provide reactive power flexibility. The flexible resources participating in this scenario were already awarded by the market (declaring their availability through bids), and their bids have been pre-qualified by the DSO in order to participate to the reactive power compensation. It is also possible to use the reactive power from a TSO level through the interconnection transformers with the TAP change possibility.	-FSP (energy storage, PVs) -Aggregators -Prosumers -DSOs -TSOs	Predicted overvoltage or undervoltage severe states in the DSO or TSO grid.		In the occurrence of a predicted overvoltage or under-voltage severe state that can endanger overall power system voltage stability. Provide/absorb of a certain amount of MVarh in specific timeframes in local distribution grid through optimized coordinated tap change control on TSO–DSO interface, through an improved forecasts of the power system state on both TSO and DSO voltage levels. It can be used to regulate voltage and reduce energy losses in the distribution grid and is linked with the voltage control. The reactive support product will be automatically activated, and the flexibility resource will provide reactive compensation to the distribution grid when needed. The activation time could be from 15 min to 1 h.
Improved power regulation through mFRR and RR	Provide identification of flexibility resources (primary, secondary and available tertiary reserve) more precisely, as well as the identification of the flexibility needs in a more precise manner and longer time period than is being done today. The activation time could be from 15 min to 1 h.	-FSP (energy storage, PVs) -Aggregators -Prosumers -TSO	Predicted available reserves in the DSO or TSO grid	High-resolution NWP with the extended geographical coverage and look into the future. Available DSO and TSO voltage level forecasted grid models.	Flexible resources will increase or decrease their active power output in order to support the frequency stability.

3.3.1. Scenario 1: Contingency Identification and Mitigation

Potential contingencies are identified (predicted) in the distribution and transmission grids via improved power system state prediction tools. The flexible resources are coordinated by the DSO and TSO to provide active power regulation services in order to relieve the local contingency of the grid. The flexible resources participating in this scenario were already awarded by the market (declaring their availability through bids), and their bids were pre-qualified by the DSO or TSO in order to participate in the predictive short-term local active product.

In order to provide/absorb of a certain amount MWh in specific timeframes in a local distribution grid, this CM product will be automatically activated, and the flexibility resource will provide peak shaving services to the distribution grid when needed. The resources could be connected to both the transmission and distribution grid. The activation time could be from 15 min to 1 h. Scenario 1 is presented in Table 4.

Table 4. Step-by-step analysis of Scenario 1.

Step No	Event	Name of Process/Activity	Description of Process/Activity	Service	Information Producer (Actor)	Information Receiver (Actor)
1.1	Weather predictions	Trigger of the scenario	Unit inside the TSO/DSO, or contracted outsourced weather forecast provider company responsible for weather forecasts for selected weather parameters and selected locations in the grid is providing us with the high-resolution NWP.	CREATE	Weather forecast provider	TSO, DSO short term planning departments
1.2	Energy predictions	Calculation of energy production and consumption	DSO/TSO Short term planning department production forecasting operator is responsible for wind, solar and hydro, short term, mid-term and long-term production forecasts, later on used for TSO level modelling under F-channel platform coordination: individual grid model (IGM) updates, DACF [1] and 2DACF [2] procedures, contingency analysis and capacity calculations.	CREATE	Production and Load forecasting operator in DSO and TSO	IGM model operators
1.3	IGM updates	Updating the INDIVIDUAL Grid Models	TSO/DSO short term planning department Expert/s responsible for development, maintenance and regular updates of an individual grid model, containing: consumption nodes (active and reactive power), production nodes (active power and voltage set), overall voltage profile, assumed power exchanges with the neighbouring systems. IGM models are further used by DACF, 2DACF and ATC calculator for further simulations, calculations and analysis.	CREATE	IGM model operators	DACF and 2DACF operators in TSO and DSO
1.4	Contingency predictions	Contingency analysis and identification of the problems in the system	An expert from TSO/DSO short term planning department, responsible for day-ahead congestion forecast simulation and analysis which, as an output, gives the list of critical elements and critical outages with the list of possible mitigation measures. If the DACF is performed by a national TSO, an analyzed system is usually only a national power system and first neighboring systems. Based on energy production and consumption predictions, grid simulation models are formed in order to be able to perform contingency analysis and identify potential contingencies in the grid.	REPORT	DACF and 2DACF operators in TSO and DSO	Power system control expert (TSO/DSO)
1.5	Mitigation measure identification	Identification of the list of potential mitigation measures	An expert from TSO/DSO short term planning department, responsible for day-ahead congestion forecast simulation and analysis which, as an output gives, the list of possible mitigation measures.	REPORT	DACF and 2DACF operators in TSO and DSO	Power system control expert (TSO/DSO)
1.6	FSP response	Evaluation of the available responsiveness of the flexible resources	Monitoring of the responsiveness of the flexible resources by the TSO and DSO in order to evaluate whether the flexible resources have the proper response to the event. The evaluation report is provided to the market operator.	EXECUTE	TSO and DSO, FSPs	Market operator

[1] Day Ahead Congestion Forecast; [2] Two Days Ahead Congestion Forecast.

3.3.2. Scenario 2: Coordinated Voltage Control

Potential overvoltage or undervoltage severe states are identified and predicted upfront. These are the states that can endanger overall power system voltage stability. In case of voltage instability, the DSO will coordinate the flexible resources to provide reactive power flexibility. The flexible resources participating in this scenario were already awarded by the market (declaring their availability through bids), and their bids have been pre-qualified by the DSO in order to participate in the reactive power compensation. It is also possible to use the reactive power from a TSO level through the interconnection transformers with the TAP change possibility.

In the occurrence of a predicted overvoltage or undervoltage severe state that can endanger overall power system voltage stability, it can provide/absorb a certain amount MVarh in specific timeframes in the local distribution grid through optimized coordinated tap change control on the TSO–DSO interface, through an improved forecast of the power system state on both TSO and DSO voltage levels. It can be used to regulate voltage and reduce energy losses in the distribution grid, and is linked with voltage control. The reactive support product will be automatically activated, and the flexibility resource will provide reactive compensation to the distribution grid when needed. The activation time could be from 15 min to 1 h. Scenario 2 is presented in Table 5.

Table 5. Step- by-step analysis of Scenario 2.

Step No	Event	Name of Process/Activity	Description of Process/Activity	Service	Information Producer (Actor)	Information Receiver (Actor)
2.1	Weather predictions	Trigger of the scenario	Unit inside the TSO/DSO, or contracted outsourced weather forecast provider company responsible for weather forecasts for selected weather parameters and selected locations in the grid is providing us with the high-resolution NWP.	CREATE	Weather forecast provider	TSO, DSO short term planning departments
2.2	Energy predictions	Calculation of energy production and consumption	DSO/TSO short-term planning department production forecasting operator is responsible for wind, solar and hydro, short term, mid-term and long-term production forecasts, later on used for TSO level modelling under F-channel platform coordination: IGM updates, DACF and 2DACF procedures, contingency analysis and capacity calculations.	CREATE	Production and load forecasting operator in DSO and TSO	IGM model operators
2.3	IGM updates	Updating the INDIVIDUAL Grid Models	TSO/DSO short-term planning department Expert/s responsible for development, maintenance and regular updates of an individual grid model containing: consumption nodes (active and reactive power), production nodes (active power and voltage set), overall voltage profile, assumed power exchanges with the neighboring systems. IGM models are further used by DACF, 2DACF and ATC calculator for further simulations, calculations and analysis.	CREATE	IGM model operators	DACF and 2DACF operators in TSO and DSO
2.4	Voltage condition prediction	Load flow and voltage profile calculation	Voltage profile for all power system substations that are in operation.	REPORT	DACF and 2DACF operators in TSO and DSO	Power system control expert (TSO/DSO)
2.5	Mitigation measure identification	Identification of the list of potential mitigation measures	Identification of FSPs that can contribute to the resolution of the identified over or undervoltage in the system.	REPORT	DACF and 2DACF operators in TSO and DSO	Power system control expert (TSO/DSO)
2.6	Provision of reactive power flexibility services	Maintain proper and efficient grid operation	The flexible resources regulate their reactive power injection to the grid to relieve congestion, improve voltage stability and power factor, and symmetrize the grid loading condition. These services are provided according to the DSO coordination set points. The provision of the services is reported back to the DSO.	EXECUTE	FSP, Aggregator, Prosumer	DSO

3.3.3. Scenario 3: Improved Power Regulation through mFRR and RR

Providing identification of flexibility resources (primary, secondary, and available tertiary reserve) more precisely, as well as identification of flexibility, is needed in a more precise manner and over a longer time period than is being done today. The activation time could be from 15 min to 1 h. Flexible resources will increase or decrease their active power output in order to support the frequency stability. Scenario 3 is presented in Table 6.

Table 6. Step-by-step analysis of Scenario 3.

Step No	Event	Name of Process/Activity	Description of Process/Activity	Service	Information Producer (Actor)	Information Receiver (Actor)
3.1	Weather predictions	Trigger of the scenario	Unit inside the TSO/DSO, or contracted outsourced weather forecast provider company responsible for weather forecasts for selected weather parameters and selected locations in the grid is providing us with the high-resolution NWP.	CREATE	Weather forecast provider	TSO, DSO short term planning departments
3.2	Energy predictions	Calculation of energy production and consumption	DSO/TSO Short term planning department production forecasting operator is responsible for wind, solar and hydro, short-term, mid-term and long-term production forecasts, later on used for TSO level modelling under F-channel platform coordination: IGM updates, DACF and 2DACF procedures, Contingency Analysis and Capacity Calculations.	CREATE	Production and Load forecasting operator in DSO and TSO	TSO (transmission monitoring system)
3.3	mFRR and RR activation necessary	Trigger of the scenario	TSO needs to activate secondary or tertiary reserve in order to maintain the frequency in the system and maintain the active power exchange on its borders like scheduled.	CREATE	TSO (transmission monitoring system)	TSO, FSP, Aggregator, Prosumer
3.4	Active power support	Provision of active power support	The flexible resources (FSP, aggregators, prosumers) provide active power support to the system. The flexible resources report to the TSO and DSO their activation.	EXECUTE	FSP, Aggregator, Prosumer	TSO and DSO
3.5	Supervision of the active power support product	Evaluation of the proper responsiveness of the flexible resources	Monitoring of the responsiveness of the flexible resources by the TSO and DSO in order to evaluate whether the flexible resources have the proper response to the event. The evaluation report is provided to the market operator.	REPORT	TSO and DSO	Market operator

3.4. Relation to Other Use Cases

As already stated, the F-channel application itself will not depend on the exact product being utilized within the market, or the market model itself (it will be possible to use it for different services and products, and different market models). At the same time, to demonstrate its usefulness and supremacy over existing similar tools and applications with various system use cases (SUCs), that will be defined and implemented under the OneNet project. The direct connection can be found with the following system use cases:

3.4.1. SUC 1: Identification of the Available Flexibility Resources from DSO and Microgrid Voltage Levels

The scope of SUC 1 is the improved production and consumption prediction, focused on a DSO voltage level, on a longer time span and wider geographical scope than the one being utilized today, through simultaneous DSO and TSO grid simulations backed up by AI-based calculation engines. Its objectives are:

- Frequency stability.
- Cost-effective operation of the system.
- Better FSPs planning and managing flexibility resources.
- Better energy predictions and power system state predictions.
- Improved identification of the available flexibility resources on all power system levels.
- Improved prediction of the system flexibility needs.

Improved production and consumption prediction for DSO and micro-grid voltage levels will allow better identification of the available flexibility resources, from residential prosumers to the centralized WPPs and SPPs connected to the distribution grid, or any local microgrid. This will occur through improved predictions and forecasting efficiency from increased spatial resolution NWPs and AI integration and its presentation with the improved observability on a higher operational control and monitoring level, including regional security coordinators (RSCs).

The F-channel application that will be developed will be capable of identifying flexibility resources more precisely and simultaneously for both DSO and TSO grid levels, mainly under OneNet, focusing on the lower voltage levels prosumers, that are usually not covered by detailed energy predictions, in a much more precise manner and over a longer time period than it is being done today. It will cover a wider geographical scope than it is being covered today by national control centers, and/or RSCs. The aim is to improve production/consumption predictions for different voltage level entities, from residential prosumers to the centralized WPPs and SPPs connected to the distribution grid or any local microgrid (local energy communities), through improved forecasting efficiency from increased spatial resolution NWPs and AI integration into the short- to mid-term power system planning simulations.

The application itself will not depend on the exact product being utilized within the market, or the market model itself (it will be possible to use it for different services and products, and different market models). It will focus on a predictive management and the need for a product. It will be possible for products from a microgrid and DSO levels to be recognized, and be available for utilization on higher voltage levels (TSOs, RSCs), as well as on the administrative aggregator's level, including identification of the flexibility resources to procure grid services.

The key performance indicators for this SUC 1 are presented in Table 7.

Table 7. Key performance indicators for the SUC 1.

Name	Reference to Mentioned Use Case Objectives
Energy production prediction error	– Frequency stability. – Better FSP planning and managing flexibility resources. – Better energy predictions and power system state predictions. – Improved identification of the available flexibility resources on all power system levels. – Improved prediction of the system flexibility needs.
Load prediction error	– Frequency stability. – Early warning on a hazardous power system regime. – Better FSP planning and managing flexibility resources. – Better energy predictions and power system state predictions. – Improved identification of the available flexibility resources on all power system levels. – Improved prediction of the system flexibility needs.

3.4.2. SUC 2: DSO, DG and Micro-Grid POI Management

The scope of SUC 2 is the registration of POIs with necessary regular periodic updates, technical data, historic data, forecasted data archiving and analysis for AI applications. Its objectives are:

- Frequency stability.
- Load flow and contingency monitoring and predictions.
- Predictive congestion management for maintaining secure and stable power system operations.
- Cost-effective operation of the system.
- Early warning on a hazardous power system regime.
- Better FSP planning and managing flexibility resources.
- Better energy predictions and power system state predictions
- Improved identification of the available flexibility resources on all power system levels.
- Improved prediction of the system flexibility needs.

3.4.3. SUC 3: Change View–Different Aggregation Level Simulations

The scope of SUC 3 is the user definition domain of DSO/Microgrid and TSO voltage level area of interest for which simulation of a power production, consumption and contingency analysis is being performed. Its objectives are:

- Frequency stability.
- Load flow and contingency monitoring and predictions.
- Predictive congestion management for maintaining secure and stable power system operation.
- Cost-effective operation of the system.
- Early warning on a hazardous power system regime.
- Better FSP planning and managing flexibility resources.
- Better energy predictions and power system state predictions.
- Improved identification of the available flexibility resources on all power system levels.
- Improved prediction of the system flexibility needs.

During SUC 3 energy predictions and system state predictions for different aggregation levels of DSO grid and local microgrid: unit level (distributed gen. unit, OHL tower/section), plant level (solar park, wind park, OHL, substation), local microgrid level (part of the DSO grid), DSO/TSO grid level simulations/calculations, depending on a selected area of interest by the end user, will be performed.

The key performance indicators for SUC 3 are presented in Table 8.

Table 8. Key performance indicators for SUC 3.

Name	Reference to Mentioned Use Case Objectives
Energy production prediction error for the selected domain	– Frequency stability. – Load flow and contingency monitoring and predictions. – Predictive congestion management for maintaining secure and stable power system operation. – Early warning on a hazardous power system regime. – Better FSP planning and managing flexibility resources. – Better energy predictions and power system state predictions. – Improved identification of the available flexibility resources on all power system levels. – Improved prediction of the system flexibility needs.
Load prediction error for the selected domain	– Frequency stability. – Load flow and contingency monitoring and predictions. – Predictive congestion management for maintaining secure and stable power system operation. – Early warning on a hazardous power system regime. – Better FSP planning and managing flexibility resources. – Better energy predictions and power system state predictions. – Improved identification of the available flexibility resources on all power system levels. – Improved prediction of the system flexibility needs.
Load flow prediction error for the selected domain	– Frequency stability. – Load flow and contingency monitoring and predictions. – Predictive congestion management for maintaining secure and stable power system operation. – Early warning on hazardous power system regimes. – Better FSP planning and managing flexibility resources. – Better energy predictions and power system state predictions. – Improved identification of the available flexibility resources on all power system levels. – Improved prediction of the system flexibility needs.
Capacity prediction error for the selected domain	– Load flow and contingency monitoring and predictions. – Predictive congestion management for maintaining secure and stable power system operation.
Transmission losses prediction error for the selected domain	– Cost-effective operation of the system.
Contingency identification rate for the selected domain	– Better energy predictions and power system state predictions. – Predictive congestion management for maintaining secure and stable power system operation. – Early warning on hazardous power system regimes.
Early warning on a hazardous power system regimes rate for the selected domain	– Better energy predictions and power system state predictions. – Predictive congestion management for maintaining secure and stable power system operation. – Early warning on hazardous power system regimes.

3.4.4. SUC 4: Improved Congestion Management Process on TSO and RSC Side

The scope of SUC 4 is the improvement in short-term forecasts, contingency analyses and capacity calculations through the utilization of the information from DSO and/or local microgrid operators. Its objectives are:

- Frequency stability.
- Load flow and contingency monitoring and predictions.
- Predictive congestion management for maintaining secure and stable power system operation.
- Cost-effective operation of the system.
- Early warning on a hazardous power system regime.
- Better FSP planning and managing flexibility resources.
- Better energy predictions and power system state predictions.
- Improved identification of the available flexibility resources on all power system levels.
- Improved prediction of the system flexibility needs.
- Improved frequency control on the TSO side.
- Improved Voltage control on the DSO and TSO side.
- Improved System adequacy on the DSO and TSO side.
- Improved Islanded operation on the DSO and TSO side.

During SUC 4, an attempt will be made to improve the power system state estimation in order to better predict system flexibility needs, with the wider geographical observability and a longer "look into the future", through improved predictions and forecasting efficiency from increased spatial resolution NWPs and AI integration and its presentation with the improved observability on a higher operational control and monitoring levels, including regional, RSC level. KPIs for SUC 4 are presented in Table 9.

Table 9. The KPIs for the SUC 4.

Name	Reference to Mentioned Use Case Objectives
Load flow prediction error	• Frequency stability. • Load flow and contingency monitoring and predictions. • Predictive congestion management for maintaining secure and stable power system operation. • Early warning on a hazardous power system regime. • Better FSP planning and managing flexibility resources. • Better energy predictions and power system state predictions. • Improved identification of the available flexibility resources on all power system levels. • Improved prediction of the system flexibility needs.
Capacity prediction error	• Load flow and contingency monitoring and predictions. • Predictive congestion management for maintaining secure and stable power system operation.
Transmission losses prediction error	• Cost-effective operation of the system.
Contingency identification rate	• Better energy predictions and power system state predictions. • Predictive congestion management for maintaining secure and stable power system operation. • Early warning on a hazardous power system regime.
Early warning on a hazardous power system regimes rate	• Better energy predictions and power system state predictions. • Predictive congestion management for maintaining secure and stable power system operation. • Early warning on a hazardous power system regime.

3.5. Products

The F-channel application will be capable of identifying flexibility resources, as well as identifying the power system state (the need for the flexibility services) in a much more precise manner and over a longer time period than is being done today. Applications will not depend on the exact product being utilized within the market, or the market model itself (it will be possible to use it for different services and products, and different market models). Nevertheless, to demonstrate capabilities of the application the following set of market products and services have been identified for the Southern cluster, demonstrated by the Greek demo in Table 10.

Table 10. Harmonization of the products identified by the Greek demo.

Products Proposed by Greek Demo	Description	Harmonized Products
Reactive support	Provide/absorb a certain amount MVarh in specific timeframes in the local distribution grid through optimized coordinated tap change control on the TSO–DSO interface. It can be used to regulate voltage and reduce energy losses in the distribution grid and is linked with voltage control. The reactive support product will be automatically activated, and the flexibility resource will provide reactive compensation to the distribution grid when needed.	Corrective local reactive
Predictive congestion management for TSO/DSO product	For a situation where forecasted or realized power flows violate the thermal limits of the elements of the grid and voltage stability or the angle stability limits of the power system. [Predictive] For congestions that are forecastable (e.g., redispatch, countertrading as well as the use of active power flexibility) grid- or market-related measures can be procured.	Predictive short-term local active
Power regulation mFRR	Provide identification of flexibility resources (secondary and available tertiary reserve) more precisely, as well as identification of the flexibility needs in a more precise manner and over longer time period than is being done today.	mFRR
Power regulation RR	Provide identification of flexibility resources (secondary and available tertiary reserve) more precisely, as well as identification of the flexibility needs in a more precise manner and longer time horizon than it is being done today.	RR
Severe state prevention/restoration product	Provide improved identification of severe system states and contingencies that can cause severe system states in a more precise manner and longer time horizon than it is being done today together with the improved identification of flexibility resources, as well as improved identification of the flexibility needs.	Predictive long-term local active

4. Implementation Plan for the Southern Cluster Demos and Connection with OneNet Architecture

4.1. Implementation Plan for the F-Channel Platform Demonstration in the Hellenic TSO–DSO-Consumer Value Chain

For the implementation of the Greek demo, a detailed implementation plan was developed early, from the beginning of the project, and was followed precisely during this 12-month period. The plan is as follows:

Task 1: Data collection and identification of relevant POIs:

- First, data collection survey.
- Identification of DSO, TSO, microgrid and DER POIs in Greece (Peloponnese and Crete).

Task 2: Technical specifications and architecture development:

- Second data collection survey: description of existing practice, standards, methodologies and software tools currently used.
- BUCs and SUCs mapping, preliminary list of actors, products and services covered.
- Requirements and system specifications.
- System architecture.
- Necessary resources.

Task 3: Development and implementation of the platform in Greece.

Subtask 3.1: Preparation of the overall development environment:

- GIT repository.
- Python development environment.
- Setting up the dedicated and allocated storage resources (Linux server, MySQL/Maria DB).

Subtask 3.2: Development and integration of the web-based, client–server application:

- Data Base development.
- App GUI development.
- AI algorithms and methods.
- Development of the cloud calculation engines.

- Connection with the external clients.

Subtask 3.3: Testing and validation of the F-channel platform.
Subtask 3.4: Demonstrations in Greece:

- Phase 1: Analysis of the predefined POIs through predefined set of Scenarios and cases to be analyzed.
- Phase 2: Benchmark with the existing tools and practice in TSOs and DSOs.
- Phase 3: Evaluation by aggregators, suppliers, consumers, system operators.

The POIs identified for the preliminary analysis are:

- All the solar parks in Peloponnese with installed power, greater than 2 MW.
- All the 50 substations in Peloponnese (in the case of 28 substations both loads alongside RES productions, are connected; while in the remaining 22 stations, only RES productions are connected).
- All the wind parks in Peloponnese.
- From the IPTO point of view, there are two potentially critical lines in the region of Peloponnese. In particular, the first POI is the OHL that connects Korinthos and Megalopoli substations, as it is a critical line concerning congestion issues. Undoubtedly, the interconnection line between Peloponnese and Crete is another POI. The aforementioned interconnection is between the regions of Sklavouna-Neapoli and Chania.

4.2. Connection with OneNet Architecture

Integration Plan of the F-Channel with OneNet

The OneNet system will provide the guideline in terms of specifying unique IT architecture which will fully support all services and the exchange of data with other modules and other partners in the project. There are ongoing discussions to identify the integration plan of the F-channel with OneNet.

The F-channel platform will be modular, allowing for the utilization of a centralized register of FSPs, or centralized market clearing tool, provided by OneNet's central system. The F-channel will be based on GeoServer technology [39], providing the rest of the OneNet partners/solutions with the state-of-the-art features related to the spatial-geo referenced presentation, simulations and analysis of the grid and all major power system elements.

The integration with OneNet's platform of platforms' will be realized following the European data exchange reference architecture, as presented by BRIDGE [40], and is depicted in Figures 9 and 10. A market clearing solution can potentially be connected with the F-channel platform, as illustrated in Figure 11.

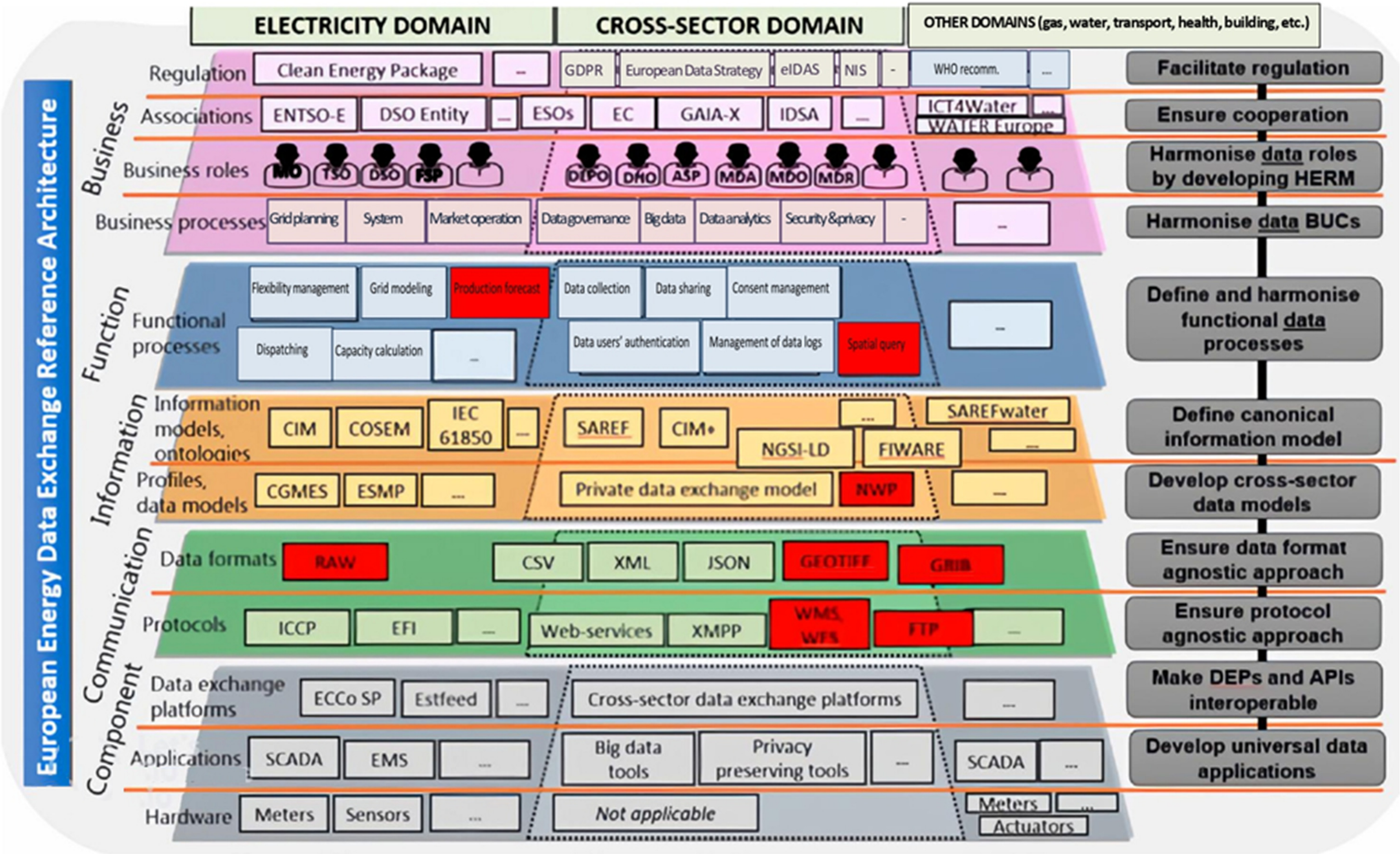

Figure 9. European energy data exchange reference architecture [40].

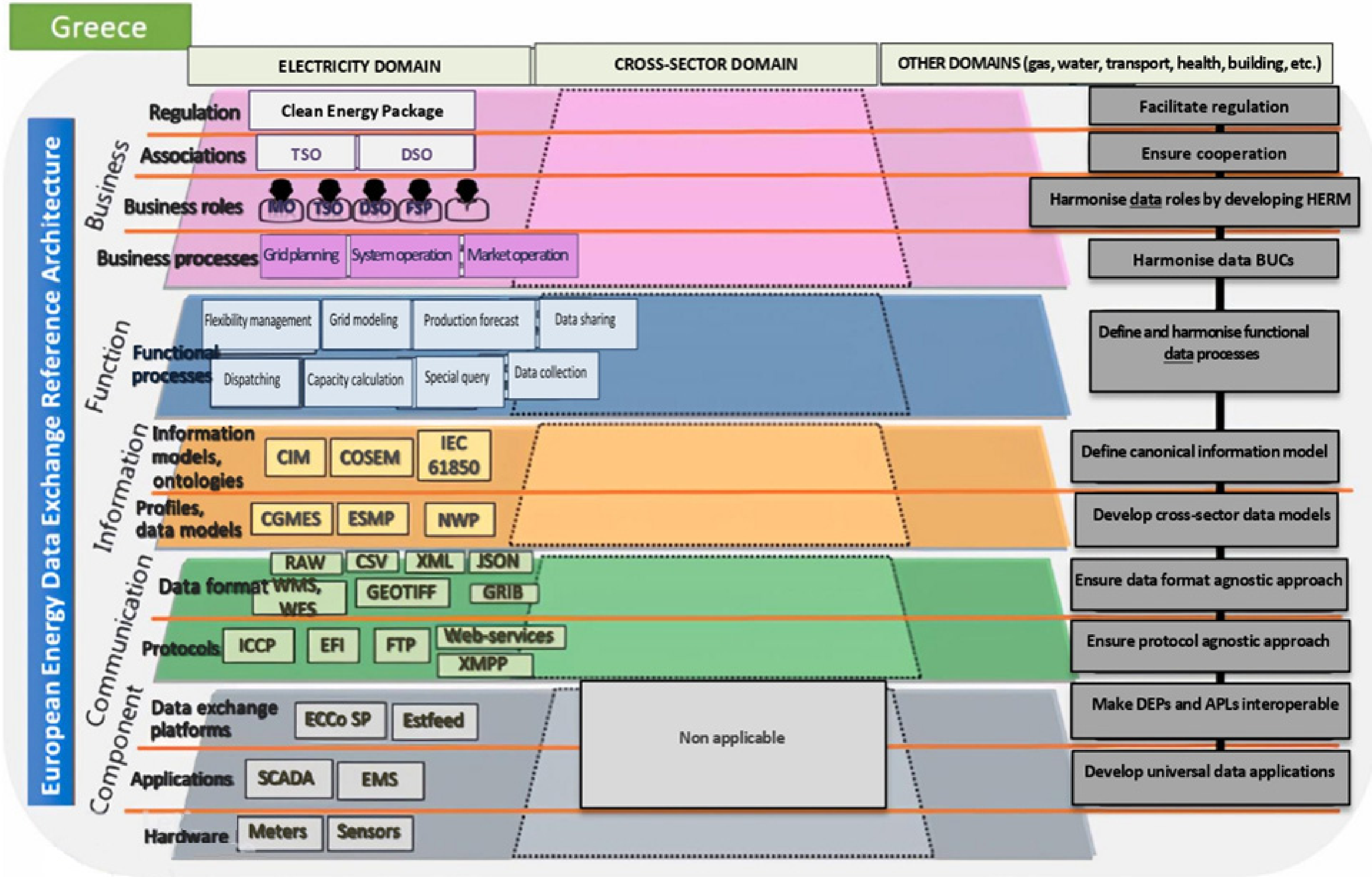

Figure 10. Identified domains for integration with F-channel.

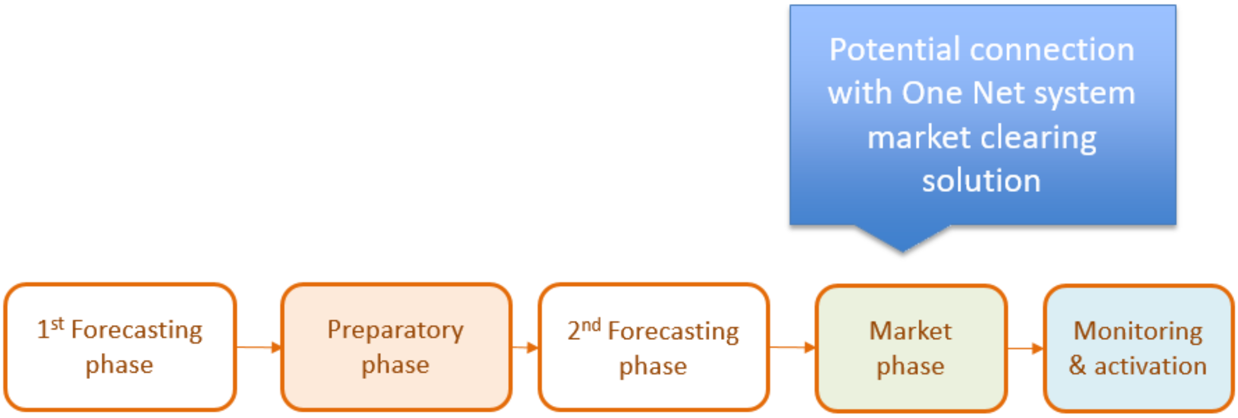

Figure 11. OneNet market clearing solution in F-channel.

5. Conclusions

The main objective of this work was to develop, design, implement and evaluate a pilot project in Greece, which tackles the challenges that system operators encounter while dealing with fluctuating renewable energy, congestion and balancing management, in accordance with OneNet's architecture. The presented work includes flexibility resources that result from better predictions and forecasting effectiveness due to greater spatial resolution, AI integration and presentation, with improved observability on a higher operational control and monitoring level. Extended analysis was performed on a business use case to avoid the power system from reaching dangerous topological or operational states by enhancing active power management for TSO–DSO coordination. Finally, it was suggested that a better state estimation of the power system has to be established in order to have greater frequency stability, cost-effective system operations and predictive congestion management. These improvements will lead to a better prediction of the system's flexibility demands.

In order to define a unique IT architecture that fully supports all services and a data exchange with other modules and project partners, the OneNet system will provide directions. It will provide operators with useful tools to monitor the operation of the distribution grid in real-time, and automatically coordinate the flexible resources located at the distribution grid in order to ensure the effective, efficient and high-power-quality operation of the future distribution grids. Effective collaboration between the TSO, DSO, market operator and flexible resources is required. This collaboration will be made simpler by the OneNet system, which permits the regular exchange of data and information between the various entities.

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